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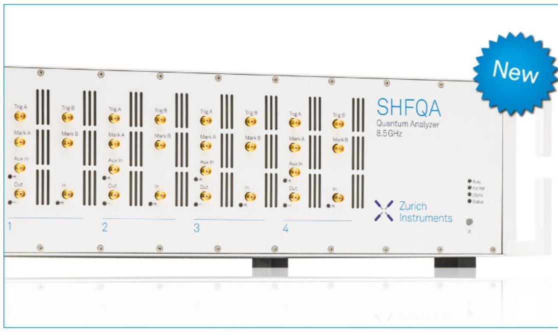
D. I. Kryuchkov, I. M. Berezin, A. V. Nesterenko, A. G. Zalazinsky, and D. I. Vichuzhanin





# Studying the Compactibility of the VT22 High-Strength Alloy Powder Obtained by the PREP Method

D. I. Kryuchkov[1, a)], I. M. Berezin[1, 2, b)], A. V. Nesterenko[1, c)], A. G. Zalazinsky[1, d)] and D. I. Vichuzhanin[1, e)]

[1]*Institute of Engineering Science, Ural Branch of the Russian Academy of Sciences, 34 Komsomolskaya St., Ekaterinburg, 620049, Russia. Tel.: (343) 375-35-90*
[2]*B. N. Yeltsin Ural Federal University, 19 Mira St., Ekaterinburg, 620002, Russia*

[a)]Corresponding author: kru4koff@bk.ru
[b)]berezin@imach.uran.ru
[c)]nav@imach.uran.ru
[d)]agz@imach.uran.ru
[e)]mmm@imach.uran.ru

**Abstract.** Compression curves are plotted for VT22 high-strength alloy powder under conditions of uniaxial compression at room temperature. The density of the compacted briquette at the loading and unloading stages is determined. It is demonstrated that strong interparticle bonds are formed in the area of the action of shear deformation. The results are supposed to be used to identify the flow model of the material studied and to perform the subsequent numerical modeling of the compaction process.

## INTRODUCTION

Powder metallurgy of hard-to-deform titanium alloys involves the use of high-cost hot compaction processes, such as gas-static or hydrodynamic pressing. Taking into account the high cost of hard-to-deform titanium alloy powders, the final cost of products made with the application of these technologies is too high to be used in civilian large-scale production. The cost of production can be reduced with the use of relatively inexpensive powdered raw materials and a rational technology. Recently, much attention has been paid to the analysis of the possibilities of using commercially available powder raw materials [1, 2]. Thus, to reduce the cost of raw materials, as a rule, mixtures of elementary powders based on titanium sponge screenings or titanium powders produced by the hydrogenation-dehydrogenation method are used. New possibilities of waste processing with conversion in powder raw materials allow using powders of high-strength titanium alloys. The industrial application of processes for dispersing blanks with a chemical composition corresponding to branded alloys makes it possible to process waste to obtain powders with spherically shaped particles. One such process is the plasma rotating electrode process (PREP). The appearance in the market of such powders obtained by processing the waste of titanium industrial production actualizes the task of finding ways of their compaction and deformation, suitable for large-scale application. To solve the problem, the method given in [3] is proposed.

## MATERIALS AND METHOD

For compacting high-strength materials with simultaneous exposure to temperatures of up to 500 °C and pressures of up to 1200 MPa, an original compression mold was designed and manufactured for work on the Instron 8801 (Fig. 1). The experimental rig contains the upper 3 and lower 4 punches, a detachable matrix consisting of single elements 5, a cage 1 into which the matrix elements, the base 2, the plugs 6 and 7 are mounted. The

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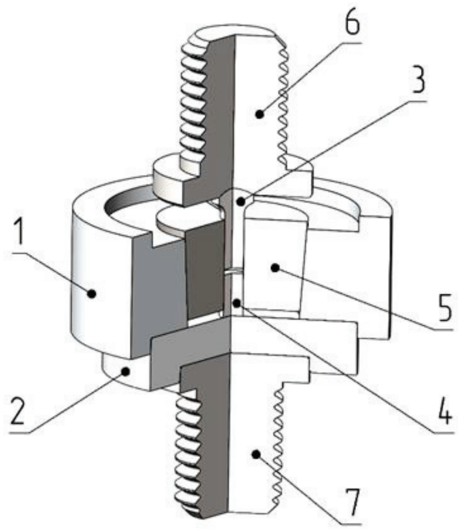
interface of the matrix 5 and the cage 1 is made in conical form. The angle of conicity of the contact surface is chosen so as to ensure that the matrix is jammed in the cage during the compaction process, while eliminating the displacement of the matrix constituent elements and the formation of gaps between them. Powder is compacted with the upper punch 3. After the end of compacting, the elements of the matrix 5 are shifted upward along the inner surface of the cage 1 and diverge, thus releasing the compact. In this case, the compact is unloaded without fracture cracks.




(a)

(b)

1 – cage, 2 – base, 3 – upper punch, 4 – lower punch, 5 – matrix, 6 – upper plug, 7 – lower plug

**FIGURE 1.** The construction (a) and the general view (b) of the compression mold with a detachable matrix

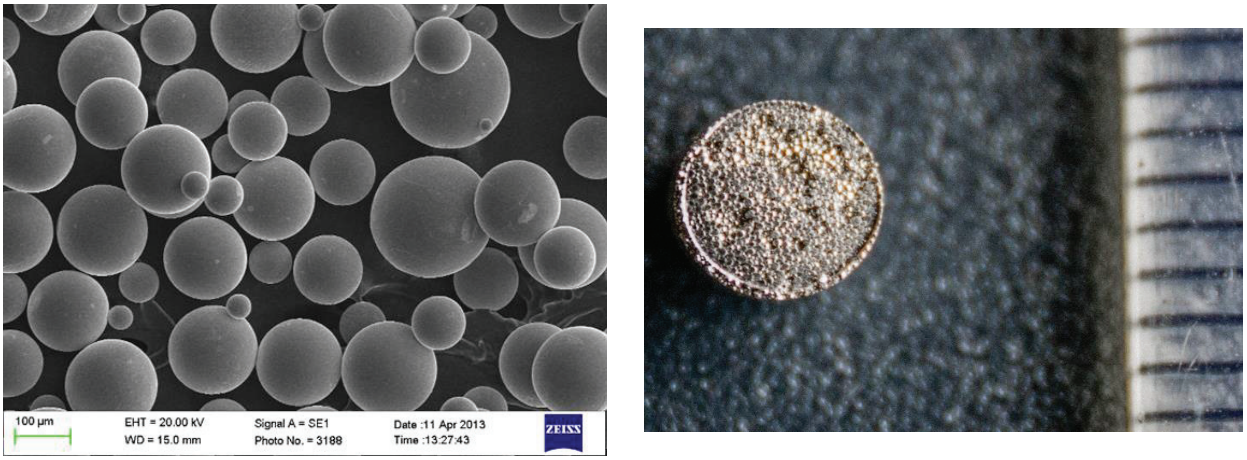
Powder of the VT-22 alloy (Fig. 2), obtained by plasma process, and developed based on the Ti-Al-Mo-V system with Fe and Cr additives, was examined. The powder particles had a round and spherical shape; their average size was 156 μm.

To verify experimentally the absence of elastic distribution of the matrix consisting of the elements 5 placed in the cage 1, a series of experiments on pressing the powder in a closed compression mold on a Tinius Olsen Super L 60 multipurpose hydraulic test machine was carried out.

To obtain a compaction diagram (the dependence of the relative density $\rho_{rel}$ on the pressing pressure $p$) and to study compactibility, a series of experiments was carried out at room temperature.

The powder was compacted in 3 consecutive loading stages. At each stage, the punch stroke, time and force were recorded. For the first loading, a force of 12.6 kN was established, which corresponds to a pressure of about 950 MPa. For the second loading, a force of 15.1 kN was established, which corresponds to a pressure of about 1150 MPa. For the third loading, a force of 15.1 kN was established, which corresponds to a pressure of about 1150 MPa. Each loading stage was followed by complete unloading with upward punch removal. The average time taken for the first, second and third loading was 67, 32 and 28 seconds, respectively. The pressing in a closed mold was carried out in a similar manner, with a force setting that corresponded to a pressure of 800 MPa.

After the experiments, the displacement-force machine diagram was processed to plot the relative density of the compacted briquette against the compaction pressure. The results were averaged based on the results of three parallel experiments.




(a) (b)

**FIGURE 2.** Morphology of the powder obtained from the VT-22 alloy by the plasma process, magnification 200 (a); example of a compacted briquette (b)

## RESULTS AND DISCUSSION

Figure 3 shows powder compacting diagrams in case of 3-stage loading. Blue indicates the dependencies obtained in the composite compression mold, red – in the closed one. $A_1B_1$, $C_1D_1$ and EF denote the first, second and third loading stages, respectively, with the use of a composite compression mold. $A_2B_2$ and $C_2D_2$ denote the first and second loadings, respectively, with the use of a closed compression mold. The K point corresponds to the powder state after the end of the third stage of loading and load removal. It can be seen from the figure that at the first loading stage the relative density increases almost linearly with the pressure. From the bulk density $\rho_{rel} = 0.595$, the powder is compacted to the values $\rho_{rel} = 0.92$ in the composite compression mold at a pressure of 950 MPa, and to $\rho_{rel} = 0.87$ in a closed compression mold at a pressure of 800 MPa. After unloading, a significant decrease in compact density is observed up to the value $\rho_{rel} = 0.74$, which corresponds to a close packing of the powder particles.

At the second loading stage in a composite compression mold, two sections can be conventionally identified. The first portion of the curve starts from a state that corresponds to close packing (point $C_1$) and extends to approximately the relative density (point $B_2$) reached when loading up to 800 MPa. In the second section, the further compaction again linearly depends on the applied pressure, repeating the dependence obtained at the first loading. At a pressure of 1150 MPa, the density approaches the theoretical one (point $D_1$, $\rho_{rel} = 0.985$). After unloading, the relative density value is reduced to 0.805 (point E). At the third stage of loading, the dependence is more hollow than at the first two, and retains its pattern to a state close to compact one (point F, $\rho_{rel} = 0.993$). After subsequent unloading, the relative density drops to 0.811 (point K).

The results of the experiments show that, during compaction at a pressure of about 1200 MPa, under load, the material is compacted to a density close to the theoretical one (points $D_1$ and F). In this case, after the load removal, the elastic aftereffect is observed. Thus, upon unloading to 800 MPa in a closed compression mold after the first loading stage, the relative density drops by 0.14 (from point $B_2$ to $C_2$).

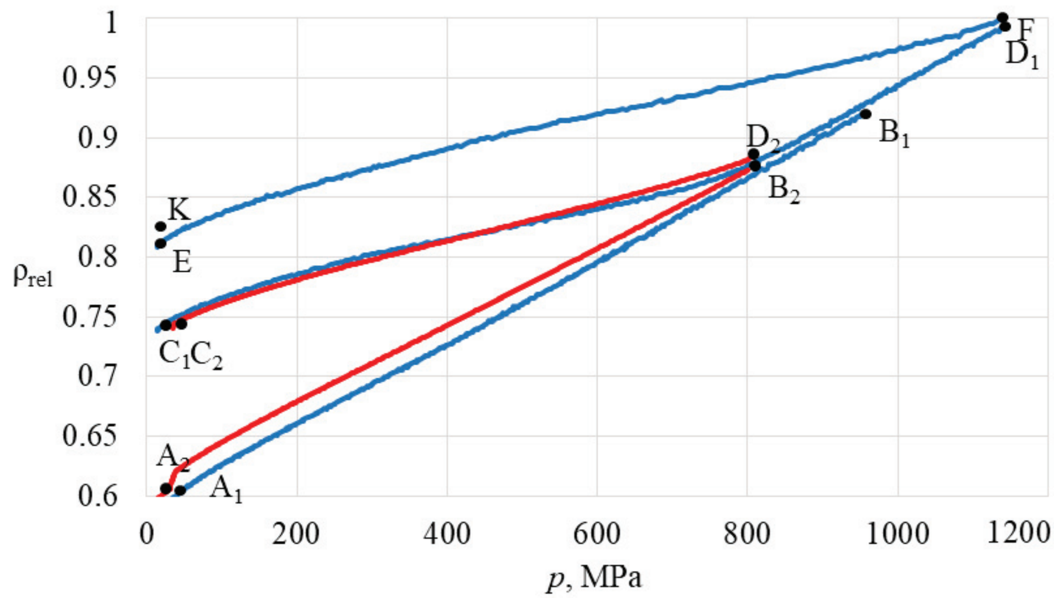



**FIGURE 3.** Dependence of the relative density $\rho_{rel}$ on the pressing pressure $p$: $A_1B_1$, $C_1D_1$, EF – the first, second and third loading, respectively, with the use of a composite compression mold on Instron 8801; $A_2B_2$, $C_2D_2$ – the first and second loading, respectively, with the use of a closed compression mold on Tinius Olsen Super L 60

An increase in pressure up to 950 MPa with subsequent load removal does not lead to an increase in the relative density above that corresponding to close packing of the powder particles (comparison of the $C_1$ and $C_2$ points). It can be assumed that at this stage, due to the applied pressure, a spatial reorientation of the particles takes place and the relative density from the bulk one increases by about 0.14, to a value corresponding to close packing. At the same time, plastic deformation of the particles is not observed. After the second and third stages of loading and load removal, the average density decreases by approximately 0.19 (from point $D_1$ to E and from F to K). Due to plastic deformation at these stages, the relative density increases by about 0.07.

## CONCLUSION

Based on the experiments conducted at room temperature in the cyclic loading and unloading regime, the compression curves of the VT22 alloy powder, obtained by the PREP method, have been constructed. The results of the study have shown that the plastic deformation of the material particles leading to irreversible densification is preceded by a spatial reorientation of the particles. Repeating the loading cycle to stresses comparable to the yield strength of the material studied in a monolithic state do not result in a strong briquette, despite the achieved relative density value of 0.811. The probable reason for this is the elasticity of the particles after the removal of compressive stresses. The visual inspection of the briquettes shows the presence of plastic deformation in the areas of maximum shear strain. These areas are characterized by the formation of a sufficiently strong bond between the powder particles.

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